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CONSTRUCTION OF CANADIAN NIAGARA POWER COMPANY'S  
100,000 H.P. HYDRO ELECTRIC PLANT AT  
NIAGARA FALLS, ONT.

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Read at Annual Meeting, January, 1905.

When the writer became Resident Engineer for this Company in August, 1901, he found that the location of the works and discharging tunnel had been already decided upon, and a shaft for tunnel construction partly sunken, and, under directions from Consulting Hydraulic Engineer Herschel, the turbine units were being given preliminary study by Escher, Wyss and Co., who also finally designed them.

Aside from the tunnel, which evidently should be built at once of full capacity, the construction then authorized was for a canal of 50,000 h.p., with temporary cribbing on the south side, a wheel pit for 50,000 h.p., and machinery and power house for 30,000 h.p.; but the company in 1902 decided to build the canal for 100,000 h.p., the wheelpit for 110,000 h.p. (one 10,000 h.p. unit as a spare), to erect a power house for 50,000 h.p., and equip it with machinery to the same extent; and this plant, along with conduits for carrying underground cables to Niagara Falls, N.Y., and to a transformer station for 25,000 h.p. outside Queen Victoria Niagara Falls Park, is now practically completed, and is in partial operation.



## COFFERDAM.

Some hazardous and approximate soundings had been taken in the Niagara River at the canal entrance, but they gave assurance that the depth of water adjacent to shore was sufficient without extending operations very far out into the rapids, and a cofferdam was built on the location shown on Plate 1., which also gives details of the cofferdam itself.

It will be noticed that these cribs, if placed separately, would have been in rather unstable equilibrium, and the contractor accordingly sunk them in pairs, with turnbuckles in place, using temporary binding timbers to hold each two cribs in correct relative position until sunken into place, after which these timbers were removed by divers.

The soundings for each crib were taken from a platform extending out over the water from the cribs previously placed, and the bottoms of the cribs were framed upside down, so as to fit the inequalities of bottom, denoted by the soundings. A floor for sustaining the rock filling was also placed in each crib as nearly as possible to the bottom, and the cribs were partly loaded before being floated into place.

In order to hold on to the cribs when placing them in a current of 10 to 12 feet per sec., several lines of wire rope operated by hoisting engines were used, and only one mishap occurred, when the bottom of the large corner crib was torn off. It was found advisable to add vertical binding timbers, not shown on plan, when cribs were to be placed in the heavy current. These are being found of advantage also during the removal of the cofferdam.

The puddle used was composed of about 2-3 gravel and 1-3 clay artificially mixed, as a natural mixture could not be obtained within a reasonable distance, and this mixture was found to fall quickly into place whenever leaks opened up, and could be rammed into a perfectly water-tight mass. It was found best, however, to keep the puddle wall well below water level on one side, so as to enable leaks to be promptly reached and the puddle to settle quickly.

The continuous decking was built in place as soon as cribs were filled with rock, and being tied across by timbers above water and turnbuckles below, the cofferdam acted as one mass.

In placing tongued and grooved sheeting, it was broomed down by hand mauls on to natural bottom, and fitted snugly around timber ties and turnbuckles, after which all openings at bottom, located by divers, were made tight by piling bags of rich cement mortar, and ramming them into the apertures.

When the cofferdam was pumped out by a battery of 12" 10" and 8" centrifugal pumps lifting about 10,000 gallons per minute, it

was found that there was, even after temporary leakage through puddle had been cut down to nominal proportions, a heavy flow of water through the boulders and gravel lying between the cofferdam and solid rock, and as this had to be handled for over two years it was considered advisable to take steps to stop it, and a puddle trench was sunk to rock at each end of area unwatered, being carried in each case from shore to adjacent points on inside of cofferdam. The cofferdam proper was sheeted on inside between these two puddle cut-off walls, with double tongued and grooved sheeting extending from above water level down to solid rock, layers of tar paper being placed between the two layers of sheeting, and in order to seal the bottom a toe of rich concrete was carried along the bottom being tied to the rock by thoroughly washing the surface of same, and spiking a heavy line of timber, about 12" above the bottom, to the sheeting.

This interior sheeting held the pressure of water against it until torn off when letting water into the canal, and the whole leakage was cut down to about  $\frac{1}{2}$  of the capacity of one 8" pump, during this period of over two years.

## BRIDGE.

The original intention of the company was to build a steel bridge across the entrance canal, to carry the tracks of the International Railway Co., and to provide width for a park drive and a sidewalk, and the plans approved by the Park commissioners showed this class of bridge.

When, however, it was decided to build the whole canal at once, the company and its engineers decided that the style of construction to be used for canal walls, power house, etc., demanded a bridge in keeping, and accordingly a stone and concrete bridge 55 feet wide, composed of five spans of 50 feet each, and costing nearly 100% more than a steel bridge and piers, was designed and built. Plates II. and III. give details of construction. The most interesting feature of design was to obtain a bridge with high springings and low crowns, as the difference in level between the water of Niagara River and base of rail was very limited. This was obtained by using steel arch trusses and concrete filling; and various studies of stone parapet walls, seeking to give satisfactory proportions and chasteness of outline have, it is believed, been successful. There are five 50 ft. spans, and when building the bridge an allowance of  $\frac{1}{4}$ " was made for settlement, but this much has not taken place, although a curious condition has arisen of the arch rings settling slightly away from the parapet walls, which carry their own weight without appreciable settlement although two expansion joints were placed in parapet walls above piers.



## CANAL AND FOREBAY.

Plates IV. and V. show the general lay out of the works and typical section of canal walls, which were carried out to the river entrance by 50 ft. curves, and from the bridge, westward, expand out into a forebay 570 feet long.

It will be noticed that these walls are second class rock-faced coursed ashlar backed with 1:3:5 concrete, and plans were also prepared showing solid concrete walls below low water, but the use of concrete as a facing to be presented to the wear of moving water ice laden, although at a slow velocity, was not approved of by Consulting Engineer Herschel, and the present plans were adopted instead, at considerably increased cost. The same remarks apply to bridge piers and to inlet breast walls.

After deducting all losses the net effective head that this plant is designed to operate under is 136 feet with all wheels running and under this head about 8870 cubic feet per sec. will be the maximum draft.

This amount of water will pass through the bridge openings at about  $2\frac{1}{4}$  feet per second with river at normal level, but in the forebay, under the same condition, the water will approach the line of submerged arches, supporting the forebay room, at only 1 ft. per second.

The Niagara river is, of course, never frozen over at the canal entrance, but after a prevailing east wind the drift ice from Lake Erie and the frazil ice formed in the rapid immediately above the works, come down in a steady flow from 50 to 100 feet wide, hugging the Canadian shore, and prepared to float into the canal whenever a flow of water creates a tendency or draft in that direction.

At first it was proposed to allow this ice to float freely into the canal and forebay, depending on the submerged arches to hold it back from the fine ice rack in front of inlets, and on the ice sluiceway shown on Plate IV. to carry it back to the river, but the writer considered a protection along the river face to be of inestimable value, and an outer ice rack was added. This rack is supported vertically by first-class masonry piers 29 feet centres, and consists of a steel footwalk with never slip plates and another steel beam some 8 feet lower; these carry 2" rods spaced 12" centres, extending  $4\frac{1}{2}$  feet below and 4 feet above meanwater level, and sloping at  $30^\circ$  with the tops down stream. This rack will keep all heavy ice out, and the swift current will roll it along the sloping rods, and should it be found desirable a steel curtain can be suspended outside the rack and down to 3 or 4 feet below water level, thus shutting out floating fine ice, but it is not expected that frazil ice can be kept

out of the forebay, as it comes down the river mixed in the water from top to bottom.

At the north end of the forebay there is a weir with three 16 feet openings, two outside and one inside the forebay room, and a fall of nearly two feet can be utilized in the winter for the purpose of creating a cross current in the forebay, thus tending to draw the floating ice back into the river, but the writer does not believe that the effect of this weir will be felt for any great distance away from the north end of the plant, although by carrying lines of floating booms diagonally across the forebay a large amount of floating ice can be poled toward the weir and thus passed back to the river; when not in use the weir will be closed by steel lift gates to above the water level of the canal.

The ice protections thus far mentioned will not keep back frazil ice, but no doubt the slow current in the forebay will allow a large proportion to rise to the surface, while the remainder will pass under the submerged arches into the forebay room, where there is a continuous line of fine ice racks resting at a  $30^\circ$  slope against the main inlet or breast walls.

These racks are carried on a steel framework, and are composed of  $3" \times \frac{3}{8}"$  bars on edge, spaced 13-16" centres, built into groups 3' 6" wide, by three tiers high; the bottom tier is 3' 0", the centre 11' 0", and top 9' 0" high, the centre ones being movable and capable of being raised up to the top, and of being held there by hooks designed for the purpose.

The functions of an enclosed forebay room will vary with the direction of current approaching the power house, and whereas this direction is parallel to power house No. 2 of the Niagara Falls Power Company, it is practically at right angles to that of the plant now being described, and therefore all floating and suspended ice adjacent to the submerged arches will, in time, pass under them and enter the forebay room, to be dealt with there by means of a travelling forebay crane, and men using rakes and poles.

However, even in this power house, an enclosed forebay room is of great value, affording comfortable quarters for men fighting ice in stormy weather, and moderating somewhat the temperature of the ice rack.

In extreme cases the centre sections of the ice rack are raised up, and the accumulations of fine floating ice and frazil are allowed to pass through the wheels, whose large ports will take care of considerable quantities of fairly large ice without any injury to the bronze runners.

The water, after passing the fine ice rack, enters 18 ft. openings in the masonry inlet walls, thence passes through cast iron penstock mouth-pieces which are elliptical ( $18" \times 12'$ ) at the outer



end and 10 feet in diameter at the inner end where they pass through the main wheelpit walls, and flows into the upper elbows of the main penstocks. During ordinary operation the movement of water is controlled by head gates set in lubricated cast iron grooves in the inlet walls, and operated by lifting screws, a box girder fastened on to the steel columns of the power house, and a 20 h.p. 125 Volt D.C. motor mounted on this girder, and for the purpose of filling the penstocks, so as to release the pressure on the gates, small hand operated wicket gates have been inserted in the main gate bodies.

Outside of these lift gates two sets of stop log grooves have been cut at each inlet, so that in case the lift gates require unwatering stop logs can be inserted.

#### WHEELPIT.

This pit, which is 570 feet long and 18 feet wide, after lining was excavated through 15 feet of boulders and gravel, 100 feet of limestone, and 50 feet of shale, the sides being separated, before blasting, by channelling. The channelling machines are self-propelling and have a travel of about 12 feet, the cuts being carried down in 6 foot benches, having 6" batter. After blasting and excavating a bench, the channelling was again proceeded with, an off-set of 6 inches being required for clearance.

For the reception of numerous castings, draft tubes, etc., a great amount of excavation was required in the form of recesses, and in order to do this without unduly shattering the side walls, the whole periphery of each recess was separated preliminary to blasting by gadding and broaching, the process being that of a drill body, mounted on a vertical column and truck, and working horizontally; by using small charges of dynamite, these detached masses of rock were then blown out, leaving the adjoining walls usually intact.

When the wheelpit for first installation of 50,000 h.p. was about two-thirds excavated, the tunnel excavation had been completed to the wheelpit, and in order to expedite the completion of the plant the writer urged that the general design should be changed, substituting two branch tunnels, turbines resting on the solid bottom, lower penstock elbows ditto, and draft tubes leading from the wheel cases to the branch tunnels, which would admit of tunnel excavation being pushed forward, and wheelpit excavation being completed four months sooner than would be the case if the lower part of the wheelpit was to constitute the beginning of the tail race.

The merits of this method had already been suggested by Escher Wyss and Co., the simplifying of the lower penstock elbow and greater solidity of the turbine unit when in operation being

evident, and, in passing, it is interesting to note that the Toronto and Niagara Power Co. has adopted this identical design for the plant they are now building. However, the view of the consulting hydraulic engineer was against the change and in order to hasten the completion of the wheelpit excavation which, on the lower levels, is very much cut up by various checks and recesses, it was decided to carry forward the tunnel excavation immediately underneath, and bring down the wheelpit excavation on the tunnel roof.

This process was fairly successful until about two-thirds completed, when the blasting from above and below had so weakened and opened up the remaining shale that wheelpit water commenced to leak into the tunnel, throwing excessive loads on the tunnel roof, and necessitating increased timbering at this place, until finally tunnelling operations had to be abandoned, and the remainder of the pit excavated in open cutting as originally intended.

The after effects of this effort to hasten operations were that the sides of the wheelpit, where excavated by tunnelling, were badly shattered, and before the brick lining could be placed large masses of shale broke away, so that as the brick lining was being put in it was necessary not only to fill up these enormous cavities with concrete, but the walls had to be continually watched and scaled down for fear of accidents.

As soon as excavation was well forward it was decided to take measurements for anticipated movement of the rock walls, and the following table will serve to illustrate what actually took place, it being understood that excavation was being carried forward continuously from March, 1902, to June, 1903, and that the measurements given are only a few of those taken.

TABLE OF WHEELPIT SQUEEZE

Measurements taken between steel plugs at centre of a pit 275 feet long, and at a point 15 feet below rock surface.

Date.	Depth of pit at time	
	Total width.	of measurement.
July 8, 1902.	20' 11 1-2"	35 ft.
Aug. 23, 1902.	20' 11 1-16"	50 ft.
Sept. 10, 1902.	20' 10 15-16"	55 ft.
Oct. 13, 1902.	20' 10 13-16"	65 ft.
Nov. 13, 1902.	20' 10 13-16"	75 ft.
Dec. 18, 1902.	20' 10 13-16"	85 ft.
March 6, 1903.	20' 10 13-16"	100 ft.
April 7, 1903.	20' 10 12-16"	110 ft.
May 8, 1903.	20' 10 25-32"	125 ft.
Oct. 15, 1903.	20' 10 7-16"	full depth.



Giving a total of 1 1-16 inches, although at lower levels a movement of 1 1-2 inches was observed between November, 1902, and October, 1903.

Not the least curious feature of these movements was the fact that the east side next the river moved about twice as much as the west side adjacent to higher ground. But the most noticeable fact of the table is that the movements, which had practically ceased by March 1903, had again become serious by October, 1903, and this had been caused by the excavation of the wheelpit extension 300 feet further, freeing one end of the rock walls. This is further shown by measurements on thrust girder castings of west wall, which had been set in September and October, 1902. It will be seen that

TABLE OF WHEELPIT SQUEEZE

Total movements of west wall at thrust girder level.

Date.	Unit 1.	Unit 2.	Unit 3.	Unit 4.	Unit 5.
Dec. 18, 1902.	— 1-16"	1-4"	7-16"	7-16"	15-32"
Jan. 27, 1903.	— 1-16"	7-32"	11-32"	7-16"	15-32"
Mar. 6, 1903.	— 1-16"	3-16"	7-16"	11-32"	9-16"
Feb. 13, 1904.	+ 1-8"	1-32"	5-8"	1 1-8"	1"

the movements had practically ceased in March, 1903, but again commenced as soon as the excavations of the extension to pit was carried down for some depth.

The first generator arch built was at unit No. 4, and during the summer of 1904 it became evident that it was being severely squeezed, and even after several heavy arches had been built, the masonry lining walls of wheelpit at the level of the springing of the arches showed slight movements. It was therefore decided to put in a few heavy cast iron struts across the pit at units No. 4 and No. 5, thrusting against cast iron strut bases, which had been provided in over 20 places in anticipation of trouble.

Four struts at unit No. 5 and two struts at unit No. 4, each of about 250 tons safe capacity, seem to have completely stopped the squeezing movement.

TABLE OF WHEELPIT SQUEEZE

At unit No. 3 after struts had been placed at various levels at Units No. 4 and No. 5.

Date.	Thrust Deck.	Turbine Deck.
Nov. 14, 1904.	18,882 ft.	16,451 ft.
Nov. 23, 1904.	18,881 "	16,447 "
Nov. 28, 1904.	18,884 "	
Dec. 6, 1904.	18,882 "	16,450 "
Dec. 13, 1904.	18,884 "	16,446 "
Dec. 21, 1904.	18,884 "	16,445 "
Jan. 2, 1905.	18,883 "	16,442 "

The lining of the wheelpit, which consists of 24 inches of solid shale brick from invert up to rack deck, and 12 inches of solid shale brick backed by 4 inches of hollow brick thence to top, is anchored to the rock walls by anchor bolts with wedges and having large plate washers embedded in the brick work, and, as the work was laid with a shove joint with one to three cement mortar, it is practically watertight, the leakage through the seams in the rock passing into the hollow brick and down openings left in the hollow brick lining to cast iron weeper boxes at the rack deck level, the water falling from them freely into the wheelpit just above tail race level.

During the placing of the brick lining a great number of castings were placed in position. These consisted of the main and auxiliary draft tubes, which were buried in the brick walls (the bracket casting section alone of each draft tube weighing about 25 tons) and castings for supporting the lower penstock elbows, guide girders, thrust girders, and the various floors placed in the pit for purposes of operation.

These latter castings varied in weight from ½ ton to 6 tons, and extended back from the face of the wall from 3 to 5 feet depending on the loads to be carried, while the lip or shoulder carrying the loads extended only a few inches beyond the face of the walls. These castings were, of course, hollow and were filled with concrete before being placed in position.

Accuracy being necessary, great care was taken as to height and longitudinal position. In placing all castings, piano wires on a reel carried heavy plumbobs immersed in water, and elevations were transferred from one level to another by a steel tape, which had been standardized at Washington, D.C. All work was carried to 1-1000 ths. of a foot, and, with very few exceptions, the results



obtained were found very satisfactory during the period of machinery setting.

On the east side three chambers, averaging about 40' x 16' x 30' high, were built at right angles to the wheelpit and just above the level of the rack deck, which is the first floor above the water in the tailrace part of the wheelpit.

They were excavated as tunnels by top headings and benches, but being in limestone did not need timbering. The lining was the same as that of the wheelpit, and they were divided up into various levels by steel floors carried on brick ledges on the lining walls.

In the extension of the wheelpit two more similar ones are being built.

These chambers contain the exciter units, the pumps for forcing water to the transformer station, an air compressor (Pelton driven) and a system of oil tanks, filters and pumps for supplying oil to the high and low pressure bearings. The machinery in these chambers will be referred to later on.

#### TAILRACE TUNNEL.

The original design for this tunnel was of a section 21 ft. high, with brick lining 16½ inches thick, but this was finally modified to the present section, which is 25 feet high, and has a composite lining, the bottom and sides being of concrete, faced with 4 inches of highly burnt brick, while in the arch a brick ring with dry packing was adhered to on account of the difficulty which would have attended the building of a concrete arch (see Plate VI.).

When the discharge tunnel was built for the Niagara Falls Power Company there was no exact information as to the value of the friction co-efficient for a brick lined channel of such large dimensions carrying water at a high speed, and even when the present tunnel was commenced, the United States tunnel had not yet been tested to its full capacity, nor properly calibrated, but an examination in the winter of 1902 showed the brick lining, although of a very ordinary quality, to be absolutely intact, unworn, and slimed over after seven years' use, with water flowing at about 26 feet per second. Still, to make assurance doubly sure, the brick facing of the present tunnel was made of a superior burnt smooth brick, and the section made about 20% larger than the earlier one, so that the velocity will be slightly increased as the grade of seven feet per 1,000 is continuous, and the alignment of the tunnel very favorable, consisting of two curves of long radius with direct outlet in line with wheelpit (see Plate IV.).

This tunnel is 2,200 feet long, including the headworks at Portal, which consists of a square headwall 60 feet wide, 12 feet

thick, and 55 feet high, extending to a depth of 35 feet below water level resting on a foundation well into the Medina sandstone; from this readwall the tunnel rises in an ogee curve for some 80 feet to the tunnel proper, and this portion is lined with 2 feet of granite, which it was considered advisable to use in place of brick, owing to the excessive speed of the water when dropping to the river level, it being understood that the invert of the tunnel at the top of the ogee curve is at the low water river level.

The excavation was carried both ways from a shaft sunk midway between the portal and wheelpit and was also carried in several hundred feet from the portal, and although the alignment was fixed from two piano wires 12 feet apart, suspended in the shaft, the instrument work at point of meeting of headings was found to be almost perfect, which must be looked on as a result of extreme care in the use of plumbobs, and taking the average of a large number of observations in this and surface instrument work.

Owing to the upper portion of the tunnel being in shale, it was necessary to carry a full timber roof consisting of 5 centred 12" x 12" rings four feet apart and three inch lagging, and these were put in place, along with the wall plates, as fast as the headings were driven, while the plumb posts, carried down to limestone, were inserted at the time the two benches were being taken up.

The original idea was to use yellow pine timber, but this was modified by substituting hemlock for centres and plumb posts, where the stresses would be compressive, and, although they were much abused by blasting, the result was satisfactory, owing to the absence of much water to soften and swell up the shale roof; the portion of roof adjacent to the wheelpit was subject to leakage when the pit excavation was being done just above the tunnel level, and at this point the roof timbers were badly crushed, and the centres settled several inches, the fibres of the hemlock segments being forced into one another.

The process of lining the tunnel was as follows:—The concrete invert (1:3:5:) being laid, the vitrified brick invert was placed as far as the corner specials, side forms were then put up and lagging, wedged back 4½ inches, was placed as high as the first course of brick headers. After the concrete side walls were built up to this height, the lagging was removed, and the brick facing carried up to and including a header course, after which the process was repeated to the springing, the only variation being that dry packing was used between and behind the plumb posts, in place of concrete shown on plans.

The brick arch was built in the ordinary way on full centres, and 4" x 4" lagging, a night man building in the key of the arch work done during the day, and laborers placing dry packing above



the haunches and driving it home against the roof timbers, also removing centres after being in position two or three days, and bringing them forward to a new position.

After side forms and arch centres were removed, the whole tunnel was scraped clear of all mortar with sharp iron tools, leaving the surface smooth and clean. It is believed that a very low friction co-efficient will exist in this tunnel, especially when the walls become slimed over with deposits from water such as have formed on the walls of the Niagara Falls Power Company's tunnel. The shaft for this tunnel was sunk from May to September 1901. Excavation was completed December, 1902, and lining and headwall in May, 1904, after which the shaft was bricked up, and outlet excavation at portal completed during the summer of 1904.

No attempt was made to hasten the completion of this portion of the plant before the machinery installation demanded it, otherwise much greater speed could have been made.

#### POWER HOUSE.

The superstructure covering the generators and switchboard, etc., is a heavy steel framed building, at present covering five 10,000 h.p. units, but the design is for a complete building 600 feet long, covering 11 10,000 h.p. units, with main entrance at the north end. (Plate VII.).

The main building is 40 feet high to the eaves, and has crane girders 31 feet above the floor, this height being necessary for proper movement of large loads from one part of the power house to another, after the machinery was installed. The proper light effect is obtained by large arch windows below the crane girders, and a series of smaller square ones just below the eaves. The exterior walls are of Queenstone gray limestone, with sufficient tooling for rich, quiet appearance; and the interior lining consists of a wainscoting of enamelled brick up to the window sills, then a belt course of green veined Vermont marble in line with marble window sills. Above this the lining will be buff brick, which will give ample light in the daytime, while at night there is an arc light on each side of the power house every 24 feet.

The roof of the main power house is of steel and terra cotta tile only, the tiles being interlocking green Ludowici, pointed with mortar; and the eaves are carried well out with a slight upward curve, ending in heavy copper gutters.

The forebay room is attached to the east side of the power house, as shown on Plate VII., and has a flat steel and concrete promenade roof, with an asphalt and tile floor. It is surmounted

by a stone parapet wall with 24 foot panels, it being proposed to place electric light columns and flower vases at the panel posts; while, for the purpose of throwing light into the room itself, in addition to arch windows every 24 feet, there is a wide continuous skylight in the roof adjacent to the power house; in the forebay room a 5-ton travelling crane spans the whole width, and will assist in keeping racks clean, and lifting them when necessary.

All the main window frames are metal, which leaves only the window sash, and small upper window frames of wood, so that practically speaking, the building is strictly fireproof. At the north end the main entrance door will be of bronze with carved side columns, and surmounted by a panel containing the company's seal; while stretching across the north end of the power house will be a visitors' gallery, from which the best view of the interior of the building can be obtained.

#### UNDERGROUND CONDUITS.

In order to convey current from the power house two lines of conduits were constructed, of the style shown on Plate VIII., one of which, 2,200 feet long, leads to a transformer station located outside the public park, and the other, one and a quarter miles long, extends from the power house through the park to the upper steel arch bridge. The four-way ducts are embedded in a one to seven gravel concrete, and are spaced generously so as to provide proper heat radiation, it being found that in a large group of cables the centre ones do not have the carrying capacity of the outer ones.

The manholes are also entirely of gravel concrete, and are drained thoroughly with six-inch tile, into which are carried the farm tile, laid alongside the ducts themselves; and a curtain wall divides the manholes into two parts, while a further separation in case of fire is obtained by soapstone slab partitions lying horizontally between each group of cables. The ordinary type of manhole carries the cables straight through without any appreciable bends, the plan shown on Plate VIII. being a special, and the 12" water main shown is for carrying water from the pumps, located in the power house, to the water cooled transformers and stand-pipe situated outside the park on the company's land.

#### TRANSFORMER STATION, ETC.

On the tableland, immediately west of their works, the company has acquired a large tract of land, and on it has been built a transformer station of 25,000 h.p. capacity, 80 feet wide by 120 feet long, having a main central room 38 feet wide equipped with a



15 ton Whiting electric travelling crane, copper oil tank, suction pump and motor, and cast iron jack rails, resting on concrete foundations. On these rails there has been installed, for the present, 12 transformers of 15,000 K.W. total capacity, fully equipped with water cooling, drainage, and lead lined oil drainage systems. These transformers are for 40,000 or 60,000 volt transmission, and are separated from the low tension and high tension switchboards by solid brick curtain walls, the cables being brought to the transformers through passages underneath the concrete floors and carried from them through overhead arches in the curtain wall, thence to the high tension switches, from which the wires will pass out of the building through specially designed windows.

The building itself is of pressed brick, with stone sills and Ludowici tile roof, and is entirely fireproof, except window frames. It has a central monitor roof for light and offices near the front entrance, which is a door of capacity for fully loaded freight cars to enter far enough to transfer loads to the crane.

Adjacent to this station has been built a stand pipe 30 feet diameter x 116 feet high, which is connected to the main water system, from wheelpit to transformer station, and the flow of water from which is controlled by a motor driven valve operated from the transformer station, the object of which is that in case of fire the stand pipe can be cut out, and the two pumps at the wheelpit, by working tandem, can raise the pressure of water to 120 lbs at transformer station floor line during the fire period.

The function of this standpipe, however, is purely one of reserve in case of a breakage of the pumping and pipe systems supplying the transformers with water for cooling, in which event the standpipe capacity is estimated as being sufficient for 50,000 h.p. for 24 hours, or for 48 hours for the present station.

In view of the importance of continuity of operation this safeguard, although costly, was considered necessary; indeed, speaking of the equipment in general, every effort was made to design the plant so as to obtain a maximum of reserve in case of breakdowns.

#### POWER HOUSE MACHINERY.

For handling materials two fifty-ton four motor electric travelling cranes were installed, which, by working with a carrier, can together handle practically 100 tons. These cranes operate with 125 Volt D.C. current, and have auxiliary five-ton hooks for fast service and light loads. The Sellers cranes, which are the ones here used, have as a distinctive feature, fixed drums, the carriage

only travelling. The speed requirements with full loads were:—main hook, 10 ft. per min.; auxiliary hook, 50 ft. per min.; trolley travel 25 to 50 ft. per min.; and bridge travel 200 ft. per min.

The main turbines have twin draft tubes emerging into the sides of the pit immediately above the invert, and, owing to the great depth of water which there will be normally in the pit with the whole plant in operation, not to speak of the effect of back water during high water in the lower river, it was necessary to locate the turbines about 47 feet above the invert of the tunnel, and although air pressure is equivalent to about 33 feet water head, it has not been found practicable to operate safely with more than 25 feet of draft tube effect, which necessitated some artificial means of creating a pondage in the wheelpit with only a few wheels in operation.

This result was obtained by installing a huge regulating lift gate at the extreme lower end of wheelpit, where connection is made with the tunnel, and operating the same by lift screws, overhead girder, and 85 h.p. 125 Volt D.C. motor (a second motor in reserve). The water will pass under the gate, and in order to resist the constant vibration, very heavy cast iron grooves, grouted and bolted into the brick lining walls of the wheelpit, rest against masonry specially cut and built into these walls to receive the grooves, and the gate is equipped with an oiling system fed from a flexible piping.

The 10,000 h.p. turbines are described as twin inward discharge, Francis type, operating at 250 rev. per min. under 136 feet net effective head, and have solid bronze runners 5' 0" diam., and cylinder gates, controlled each by four racks and pinions. The racks move on opposite sides of the pinions, so that one gate rises as the mate to it lowers, the whole movement for each unit being controlled by a connecting rod from the Escher Wyss governor situated on the power house floor.

The revolving parts of a turbine and generator, and the shaft connecting them, are supported as follows:—In addition to the upward thrust on the upper runner, there is a balancing piston located immediately above the wheel case, and the piston for each unit is directly supplied with water from the forebay by a twelve inch pipe, but as a reserve, in case of accident, there is also a connection with each penstock.

In addition to this there is attached to each main shaft immediately beneath the generator a thrust bearing, capable, when operated with high pressure oil, of carrying the whole weight of the revolving parts of a unit, which amounts to about 243,000 lbs. This bearing is fed from the oil chamber with oil, which is raised to a



high pressure by a pump located immediately alongside on the thrust deck; after leaving the bearing the oil flows back to the chamber to be cooled, clarified, and pumped back again to the thrust deck. The turbine shafts are hollow seamless cylinders 40 inches in diameter with weldless flanges, which connect by couplings to nickel steel bearing shaft 14 inches diam., bored out 8" at the various bearings and connections, there being, as shown on Plate IX., two intermediate bearings for supporting the shaft between the thrust bearing and balancing piston.

The main penstocks each consist of a lower cast steel elbow in two sections, weighing 49 tons, which sits astride of the pit and carries the weight of the penstock and the water contained therein; above this are five straight sections of rivetted pipe ten feet two and a half inches in diameter, having weldless steel flanges, and an expansion joint connecting to the cast iron mouthpieces in wheelpit wall by a steel upper elbow. The calculated speed of the water with full load on a unit is about 11 feet per sec.

Fire units of 7,500 K.W. output each, makes the present installation, but the plant is built for eleven such machines, the eleventh being counted a spare, and in order to increase the present output it will only be necessary to extend the power house building and install such machinery as may be required.

For supplying the various water-driven machines in the chambers, an independent water system has been installed, which consists of a 36-inch rivetted main with weldless flanges, along the rack deck, fed from the canal by two 36-inch and five 24-inch vertical pipes. Of these, one 36-inch and two 24-inch pipes are in the first installation. From this main, which is sub-divided by valves at various points, rising pipes enter the chambers and, after operating the machines, the water passes by draft tubes into the tailrace below.

In one chamber is located an exciter plant, making 125 Volt D.C. current, which is used not only for excitation of large generators, but for operating cranes, switches, various gate and pump motors, and lights, etc. This plant consists of three vertical direct connected units of 332 h.p. each, the turbines being single, spiral case, inward and downward discharge, running at 600 rev. per min. under 131 ft. head, and controlled by Lombard governors. These units have oil bearings supplied with low pressure oil from the oil chamber, and are each quite independent, so that any unit can run with the other two shut down for repairs.

In a second chamber are located two pump units. Each unit consists of a horizontal turbine direct connected to a centrifugal pump of 3,000,000 galls. per 24 hours capacity. These pumps can,

as before remarked, be run in tandem in case of fire so as to produce a fire pressure at the transformer station of 120 lbs., with a pressure at the pump of 210 lbs. per sq. inch. The turbines are driven from the 36" auxiliary main and discharge into the tailrace by draft tubes built into the brick wheelpit lining, while the pumps draw their water from one of the 24" supply pipes from the canal and discharge by a 24" pipe up the wheelpit, and thence out and to the transformer station, a half mile distant, by a 12" water main.

In a third chamber there is a very complicated system of motor and Pelton driven Quimby screw oil pumps, oil tanks, filter tanks, and cooling tanks, all so inter-connected as to produce necessary circulation, which consists, briefly, in there being two circuits, one for low pressure and one for high pressure oil. The oil traverses from a machine back to the cooling and filter tanks, thence to the suction tanks, from which it is again pumped back to the machine. The high pressure oil is handled in the same manner, except that a special pump is located at each thrust bearing, and raises the oil pressure at these bearings, after which this oil also flows back to the oil chamber to be cooled and clarified. In this chamber is also a specially designed Pelton driven air compressor, and in a chamber on the upper level adjacent to the main subway are located storage tanks of large capacity for storing oil, while a pressure oil tank is also located in the roof of the power house.

The main power house floor will contain only three items of equipment, namely, the 7,500 K.W. generators, the turbine governors, and the main switchboard. So that the view from the visitors' gallery will be one of extreme simplicity, as the armatures of the generators are external and stationary, and the governors are very innocent looking machines in line with the generators, and not observable from the north end of the power house. The generators are about eighteen feet in diameter, with internal revolving fields, and deliver three phase 25 cycle current at 12,000 volts, which was adopted in order to enable local distribution for several miles to be made without transforming.

As these generators were both too large and too heavy for transportation it was necessary to have them completely assembled at the shops, then taken apart and packed in hundreds of boxes, and shipped knocked down to the works, where it took several months to re-build the fields and armatures piece by piece, there being, it is understood, 47,000 punchings in each armature.

Plate IX. shows two subways just below the power house floor, one to the right being for cables, and the main one to the left for cables and for the substructure of the main switchboard, which, for each 50,000 h.p., is about 150 feet long. The subway itself runs the full 600 feet length of the plant, and has a series of chambers open-



ing off to the left, one at each inlet breast wall, which will be devoted to miscellaneous purposes, such as location for small transformers, etc. The main switchboard consists of a lower part in the subway, made up of bus-bar compartments, divided up vertically by brick walls and horizontally by soapstone slabs, and containing motor operated oil switches, and above the power house floor the switchboard proper from the gallery of which a full view of the power house is had, and which is equipped with switches necessary for full control of the station.

Cables leave the power house by three manholes, one situated at each end and one at the west side, from whence they pass through conduits, already described, either to the transformer station or to Niagara Falls N.Y., to deliver current supplementary to that generated by the Niagara Falls Power Company. These cables are lead covered,  $2\frac{1}{2}$ " diameter, and contain three phase 19 strand copper conductors, each  $\frac{1}{2}$  inch diameter, which are insulated by paper and gum wrappings, the whole three being again insulated by similar wrappings beneath the lead covering.

The ground for this plant was broken in September, 1901, although the tunnel and cofferdam had been nominally commenced somewhat earlier, and water was turned into the forebay Nov. 9th, 1904, the exciter chamber was ready for operation Nov. 24th, 1904, and the 1st 10,000 H.P. unit December 23rd, 1904,—while two 10,000 h.p. units were ready for operation January 1st, 1905. The third units will be put in operation in a few months, and the fourth and fifth units during the summer of 1905, while the extension of wheel-pit complete, brick lined, and ready for the machinery of the remaining six units should be completed during 1905.

It will be appreciated that during this period, Queen Victoria Park, with two other large and one smaller plant under construction, was in a state of great chaos, and this is largely the case at the present time, but the companies are under obligations to place their respective areas in good condition as soon as construction is finished, and when this has been done the southern part of the park, which was always in a state of nature, will be vastly improved. The Canadian Niagara Power Company, in process of construction, filled in the foreshore of the river for about 100 ft. in width from the Horseshoe Falls southward for over  $\frac{1}{2}$  mile, and this will be also sodded and added to the park area.

The principal contractors connected with the works were:—James Barry, cofferdam; Dawson & Riley, wheelpit and canal; Queenston Quarry Co., arch bridge; A. C. Douglas, tunnel and portal; Wm. Grace Co., power house; Brass Bros., transformer station; Escher Wyss & Co., turbine units No. 1, 2, 3; I. P. Morris Co., turbine units No. 4, 5; General Electric Co., generators and main switch-board; Jenckes Machine Co., exciter turbines; West-

inghouse Electric and Manufacturing Co., exciter generators; Canadian General Electric Co., transformers; Canada Foundry Co., various lift gates, etc.; Hamilton Bridge Co., power house steel work; in addition to which a great many contracts were placed in Canada and United States for various pipings, steel floors, smaller machinery, etc. The policy was at once established of having continuous and thorough inspection in keeping with the rigid specifications and high-class of work demanded, and a large number of inspectors were employed, who were located at the various manufacturing centres and on the works itself. As these men were all the best that could be found for the various classes of work being done, it is believed that the results warrant the large attendant expenditure. For mill material, the Pittsburg testing laboratory did the inspection.

For the complete study, design, and execution of such an undertaking as has just been described, the engineering department was necessarily somewhat complex, there never having been any chief engineer, either nominal or actual, the organization being as follows:—Chief mechanical engineer, Dr. Colman Sellers; consulting hydraulic engineer until December 31st, 1903, Clemens Herschel; consulting engineer until March 1st, 1904, W. A. Brackenridge; resident engineer in charge of construction, Cecil B. Smith; Electrical engineer, H. W. Buck.

Speaking generally, the designing was done under the direction of Consulting Engineer Brackenridge and by the designing staff of the Niagara Falls Power Company in charge of A. H. Von Cleve until March, 1894, since which time the writer assumed Mr. Brackenridge's functions, but the liberal policy of the company was, that all the main points of design were determined after full discussion by the various engineers mentioned.

In carrying on the work of construction the company allowed the writer full choice of whatever staff was considered necessary, and to employ also such inspectors in different branches as were needed. The chief assistants were as follows:—Principal assistant engineer, G. A. McCarthy; assistant mechanical engineer, C. C. Egbert; assistant electrical engineer, G. E. Brown; assistant engineer of wheelpit and canal, Wm. Macphail; assistant engineer of tunnel, L. Sherwood.

To these gentlemen the writer wishes to here tender his extreme appreciation of those qualities which made it possible to carry on such an extensive work with satisfactory results, and in that harmonious spirit which prevailed from the commencement of the work until the time (Dec., 1904), when the writer completed his engagement with the company.



10' 0"

26' 0"

8' 0"

8' 0"

6" x 12" x 1' 6" Block

3" Sheeting, tongued & grooved

1/4" x 15" Machine Bolts

8" x 6" x 1/2" W.I. Plate

1/2" Rods 4 sets to each section of cofferdam  
Length to be determined after cribs are in place.

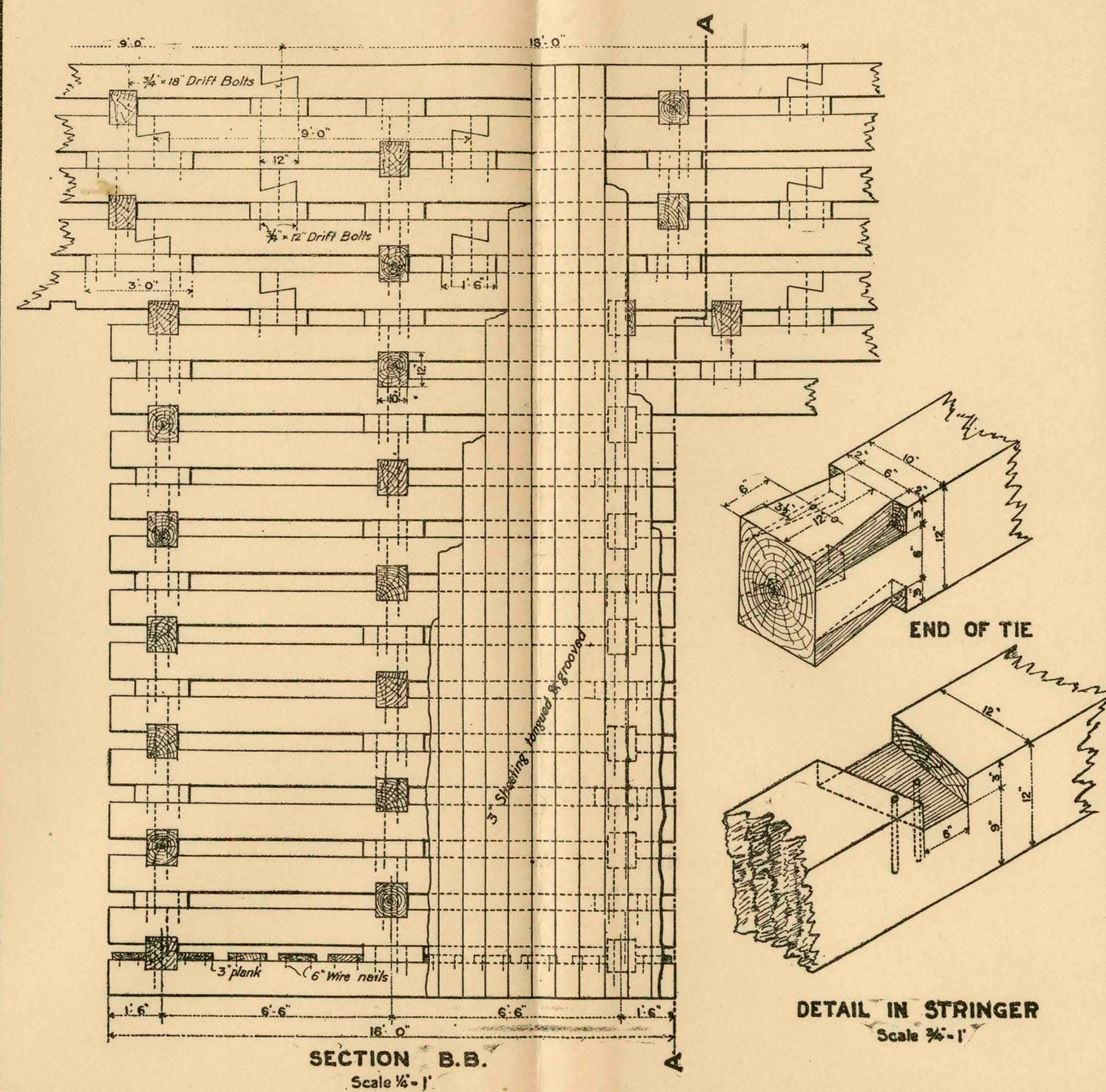
6' x 12"

3' 4"

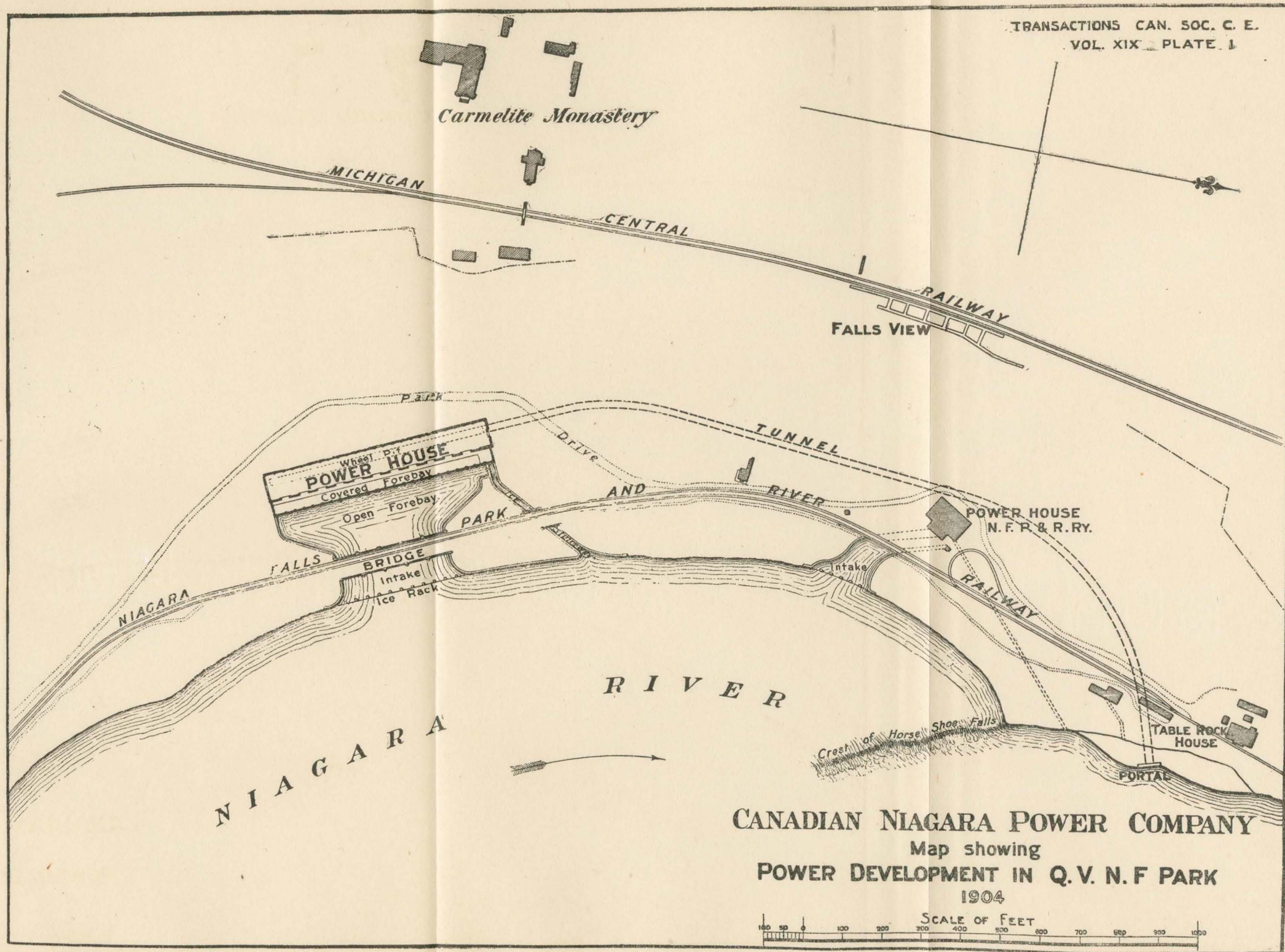
2' 4"

SECTION A.A.

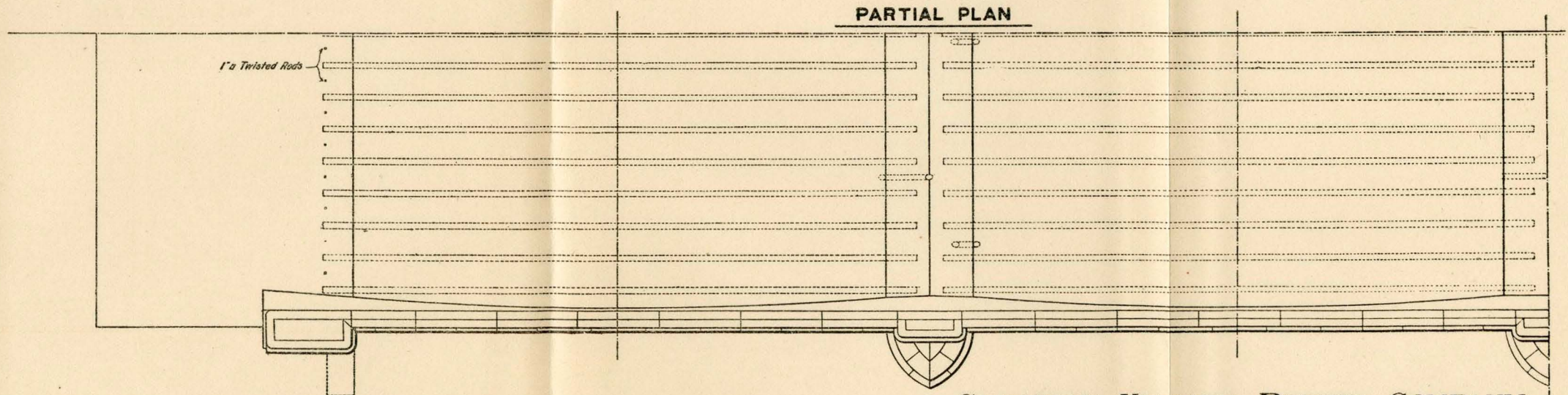
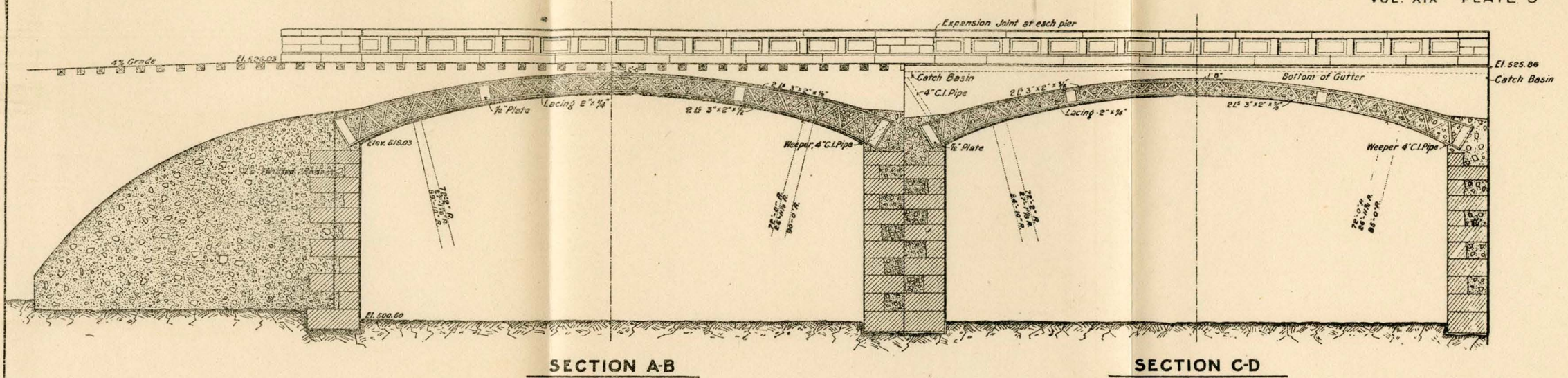
Scale 1/4" = 1'



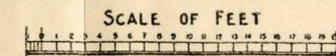








CANADIAN NIAGARA POWER COMPANY  
STONE BRIDGE OVER CANAL INLET





## CANADIAN NIAGARA POWER COMPANY

SECTION OF CANAL WALL  
AT BRIDGE ABUTMENTScale  $\frac{1}{4}$  inch = 1 foot